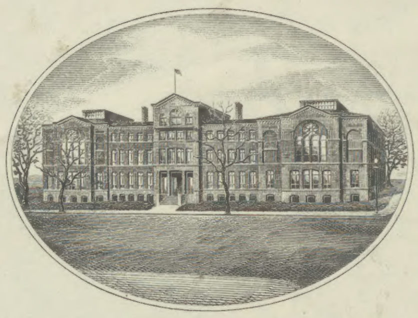
U. S. Aero Medical Laboratory,
Wright Field, Ohio

Synopsis



SYNOPSIS
OF THE
AERO MEDICAL ASPECTS
OF
JET PROPELLED AIRCRAFT

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Prepared by the Staff, Aero Medical
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Prepared: January 1949

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INTRODUCTION

To the flight surgeon of World War II, modern jet aircraft have introduced operationally no new principle nor any new care-of-flyer problem that did not exist previously in some form for the conventional P-47 and P-51 fighters and for the B-17 and B-29 bombers. For these older aircraft, operational flights above 30,000 feet were only occasional; for the jet type, such flights are routine. For the older fighters, speeds up to 600 mph were only possible in steep dives, but for the jet fighters, such speeds in level flight are routine. During the past war, the only pressurized aircraft used in service were the B-29 and the C-69. Today, all jet aircraft are pressurized. In short, jet propelled aircraft have made routine many operational conditions considered as special cases during the last war.

The most strikingly new field of aero medical research and development introduced by jet aircraft is the problem of emergency escape from these high speed and high altitude aircraft. In evaluating the human design requirements for an ejection seat, it has been necessary to study human tolerance to very high G-forces acting for short periods of time. Similar forces have been observed before in aircraft crashes and ditchings and in high altitude parachute opening shock. For these latter problems a negative solution, of avoiding the issue, has been followed. However, the ejection seat program has caused indirectly a complete revision of our concepts of human tolerance to short time

high G-forces and has resulted in an entire change of thinking in this important field.

A second new post war field of research is what has been rediscovered and renamed as "Human Engineering". During the past war the Air Force pioneered the use of anthropometry in sizing cockpits, gun turrets, and escape hatches. Physiological and biophysical principles were used to define human requirements for pressurizing and air conditioning aircraft cabins. In the literal sense, all this was and still is "human engineering". However, in its newer usage, human engineering covers primarily the psychological relation of man to his machine. Psychological engineering has made its greatest contribution in establishing new requirements for design of flight controls and flight instrumentation. For jet aircraft, where the tempo of flying, navigating, and landing is greatly accelerated, the effectiveness of a flight control or instrument may spell the difference between success or failure of a mission or be the deciding factor in flying safety.

A third new post war field of aero medical research is that of ultrasonics. When jet aircraft were first introduced, this form of sound was thought to be a significant flight hazard. Since that date, the entire sound spectrum occurring during jet flight has been analyzed and re-evaluated biophysically. It has recently been shown that the real sonic hazard may come from the lower sub-auditory frequencies rather than from the so-called ultrasonic.

In the following sections, brief summaries are presented of aero medical problems arising today from the use of jet aircraft. In many sections nothing

new has been added since the war, except a better understanding of human requirements. In others, such as indicated above, much new material has been included and many new problems clarified.

Oxygen Requirements for Jet Aircraft

Physiologically, when 100% oxygen is respired without pressure breathing, a pilot's performance is subject to increasing handicap above 40,000 feet (141 mm of Hg pressure). Above 40,000 feet, an ideal pressure demand oxygen system should be designed to maintain a 40,000-foot "equivalent oxygen altitude" by supplying oxygen under a pressure equal to the difference between the ambient pressure and 141 mm Hg. A simple calculation reveals that a breathing pressure of 29 inches of water (54 mm Hg) is required at 50,000 feet to maintain this 40,000-foot "oxygen equivalent". High breathing pressures at this level can be used even with respiratory aids by thoroughly indoctrinated individuals for periods of only 4 minutes before onset of nausea, diaphoresis, and impending syncope. At pressures of about 20 inches of water, the duration of the symptom free period is lengthened to approximately 12 minutes, following which the effects of reduced cardiac output resulting from greatly increased venous pooling become evident.

In actual practice, when using pressure breathing above 40.000 feet with the standard A-13 pressure demand oxygen mask and the A-14 pressure demand regulator, a compromise solution must be sought in which a certain degree of hypoxia is accepted in exchange for a gain in altitude. The minimum breathing

pressure at which oxygen must be delivered to maintain useful consciousness for at least one minute at 50,000 feet and then to permit safe descent to 10,000 feet at a rate of 10,000 ft/min is 14 inches; 10 - 12 inches and 8 inches of water are required to maintain the required useful consciousness and performance at 48,000 feet and 46,000 feet, respectively, under similar conditions. These data are based on a small group of subjects who were thoroughly indoctrinated in the use of pressure demand equipment. A number writing test was used as a qualitative measure of the degree of hypoxia present. Results indicate that there is one important limitation imposed by present pressure demand oxygen equipment: the difficulty of holding more than 14 inches water mask pressure without pressing the mask tightly against the face with the hand.

From a practical point of view it is felt that operations above 40,000 feet should be undertaken within the confines of a pressurized cabin and that the increasingly high breathing pressures required to maintain useful consciousness from 40,000 feet to 50,000 feet should be used only in emergency loss of this cabin pressure.

Oxygen Equipment for Jet Aircraft

The pressure demand oxygen system consisting of an A-13A mask and an A-14 oxygen regulator, whose use was pioneered by Air Force Photo Reconnaissance Units during the last war, is now the standard oxygen installation in all jet

aircraft. This system has two advantages over the conventional demand oxygen system used as standard during the past war. First, it provides a positive safety pressure and eliminates in-board mask leakage when used in the 30 to 40,000-foot range. Secondly, it provides an emergency pressure breathing source of oxygen for use up to 50,000 feet.

The entire installation itself, as used today, is practically the same as used at the end of the last war. It consists of a set of low pressure oxygen cylinders manifolded together and connected to a common filler valve accessible from the outside of the airplane for recharging. The cylinders are interconnected by the use of check valves in such a way that battle damage to one or more cylinders will not result in a complete loss of the available oxygen supply. The cylinders are made from stainless or low alloy steels and are designed not to shatter when pierced by 50 caliber incendiary ammunition and when filled to a working pressure of 400 psi. The oxygen tubing leading from the cylinders to the various oxygen stations throughout the airplane is aluminum alloy, having an outside diameter of 5/16 of an inch with an 0.032 inch wall thickness. Each oxygen station consists of a pressure gage, a flow indicator, a pressure demand oxygen regulator fitted with a flexible outlet hose and receptacle for inserting the oxygen mask connector; and in bombers, a portable oxygen cylinder and regulator assembly, a recharger hose assembly for recharging the portable cylinder in flight is also included. The pressure demand mask itself is issued as personal equipment. The present bailout system, Type H-2, consists of a non-shatterable high pressure cylinder. The

oxygen flow is lead into a "T" connection at the disconnect end of the mask tube. This connection is check-valved and orificed so that 10 - 12 inches positive pressure is applied to the mask on the initial flow of oxygen, which is started by pulling a cable leading to a break-off nipple at this cylinder.

Plans for a future design of the pressure demand system include greater mask comfort, integration of the pressure gage and flow indicator with the pressure demand regulator, automatic control of both the air-oxygen ratio and the mask breathing pressure with changing altitude. In addition, the entire instrument will be designed for panel mounting, for easy removal and for test or repair.

Decompression Sickness

Although decompression sickness is not a serious hazard currently, in jet operations its future significance during high altitude flights, even with cabin pressurization, is worth passing mention.

The most recent summary of the practical effect of decompression sickness on flight operations was recently given by Smedal and Hall in the November issue (1948) of the USN Medical News Letter. Their joint conclusions and observations are summarized briefly as follows:

a. Severe symptoms below 23,000 feet are unlikely.

b. For each 100 man hours at 25,000 feet, there is a single probable incident of decompression sickness serious enough for flight termination, and ten incidents tolerable and without flight termination.

c. For each 100 man hours at 30,000 feet, the serious incident rate is three and the tolerable incident rate is thirty.

The incidence rates observed above during actual flight cover moderate muscular activity but no preoxygenation.

In practical terms, as applied to single place jet aircraft, it can be seen that for a 25,000-foot cabin altitude on a 4-hour mission the probability of abortion on account of decompression sickness is one in twenty-five. For a four place jet bomber on an eight-hour mission, the probable abortion rate would be one in three, if a 25,000-foot cabin altitude were used throughout the flight. At 30,000 feet compared to 25,000 feet, the probable abortion rate would increase approximately three times.

Preoxygenation or the use of 100% oxygen from the ground up will greatly reduce the probability of decompression sickness below the figures listed above. A reasonable evaluation of this reduction is approximately threefold, a figure based on our own unpublished experience in the Laboratory. For all experimental flights where ambient pressures above 35,000 feet may occur, one half hour preoxygenation and 100% oxygen from ground up, as a standard operating procedure, has been used at Wright Field to date with almost complete success both in the altitude chamber and in actual flight.

Cabin Pressurization

That all operational aircraft capable of flight above 20,000 feet must have cabin pressurization is now well accepted by both commercial and military

aviation as the most effective protection for airmen and passengers against the effects of hypoxia and decompression sickness.

From the viewpoint of protection against hypoxia there are three methods of applying cabin pressurization:

By the first method, the cabin is maintained at altitude levels for which continuous use of oxygen equipment will not be necessary.

By the second method, supplementary oxygen is used continuously but the cabin altitude is maintained at levels below which incidence of decompression sickness is operationally insignificant.

By the third method, for flights above man's oxygen ceiling, 40,000 feet, only sufficient pressurization is used to maintain normal oxygen altitudes and to avoid need for higher levels of pressure breathing (other than safety pressure).

The application of these methods outlined above vary considerably in actual practice.

For jet aircraft of the fighter type, the Air Force uses the second principle method of pressurization. For flights above 10,000 feet, this constant isobaric level is maintained to 18,000 feet, above which a differential pressure of 2.75 psi with ambient pressure is used. Above 38,000 feet, the cabin differential pressure is gradually reduced by a special control such that the relative gas expansion (RGE) for wet gases at body temperature is held to approximately 2.3. As will be seen in the next section, this over-ride control is necessary to protect the pilot from the effects of

explosive decompression. The first advantage of this type of control is that to flight altitudes of 43,000 feet cabin altitude is never above 30,000 feet, at which level decompression sickness is perhaps significant but not serious for a fighter pilot. The second advantage is that manual decompression of the cabin before ejection of the canopy preceding use of the ejection seat is unnecessary. The disadvantage of this system is the lower protection given the pilot against decompression sickness compared to use of a differential of 3.25 psi, as used by the RAF, or 5.0 psi as recently proposed by the U. S. Navy. Neither of these higher values are practical, if the danger of explosive decompression is to be avoided. However, in two years of F-80 operations, no authentic case of decompression sickness has been reported as a result of using the 2.75 psi differential itself.

In actual practice, the 2.75 differential and the RGE over-ride control is considered mechanically feasible by manufacturers of cabin pressure regulators. Higher operating differentials have proven to result in excessive leakage occasionally and increased structural weight of the fuselage. Higher operating differentials also reduce the effectiveness of expansion air-cycle coolers now necessary to air condition all high speed aircraft.

The first method of pressurization is used for all Air Force bombers for which a maximum differential pressure of either 6.55 psi or 7.45 psi is required with a 5000-foot isobaric. In the B-29, B-36, B-50, and cargo types, no RGE over-ride control is necessary to protect aircrews from the hazard of explosive decompression , because of the inherent protection given by the

large cabin volumes of these aircraft in relation to the probable area of damage to cabin surface. However, for the medium jet bomber class, namely, B-45, B-47, and B-48, and RGE over-ride control is necessary. The proper RGE value is chosen on the basis of the maximum expected area of the cabin wall to be damaged by enemy gunfire in relation to cabin volume. In the B-45, for example, the 5000-foot isobaric cabin altitude is maintained to 28,000 feet flight altitude above which the 7.45 psi differential is used. Because of a very large, removable canopy in relation to its cabin volume, in combat areas a 2.4 RGE over-ride control is activated. Cabin levels below 28,000 feet are maintained up to flight altitudes of 40,000 feet.

The third method of pressurization is used only in experimental aircraft, such as the Bell X-1. For pilots of these few aircraft, thorough indoctrination in use of oxygen equipment is possible and preoxygenation gives the necessary protection against decompression sickness.

Explosive Decompression

Problems which are inherent in the design and operation of present day jet aircraft and which have been produced as a result of man's limited tolerance to explosive decompression are by and large not essentially different from those foreseen in 1945, when experimental studies defining the upper limits of man's tolerance to explosive decompression were completed. The resulting data from these earlier experiments have been summarized mathematically and graphically and published in the literature in a form useful to aircraft designers,

The above earlier work demonstrated that, when the relative gas expansion (RGE) in the lungs, as calculated by the formula,

$$\text{RGE} = \frac{P_c - 0.91}{P_a - 0.91}$$

where P_c = absolute pressure of cabin in psi,

P_a = ambient flight pressure in psi, and

0.91 = vapor pressure of water at body temperature, 98.6°F., in psi,

was 2.1 or less, the danger from decompression was independent of the time of decompression. For tolerable values of RGE above 2.1, the relation of the probable area of exploding orifice to the cabin volume must be considered. Present formulae for predicting the danger of explosive decompression have been validated up to 50,000 feet by human experimentation.

It should be pointed out that in view of what is known about the inherent strength of the mammalian lung as a mechanical structure, the tolerance limits predicted above may be low and on the conservative side. These limits were based on results obtained experimentally on subjects who were using pressure demand equipment set at safety pressure. The criterion used in these experiments to indicate the upper limits of safety was the occurrence of twinges of pain in the region of the diaphragm during the explosion. Caution must be exercised in applying these simple criteria to decompressions to very high altitude above 50,000 feet and during which pressure breathing is used at levels above the safety setting (2 inches of water pressure).

Another aspect of the problem of explosive decompression in high altitude flight may appear when jet aircraft begin operating at flight altitudes between 45,000 and 50,000 feet for periods of several hours. Under such conditions, it may be necessary, even in combat, to operate continually the cabin altitude at the 30,000-foot level, or below, in order to preclude the onset of incapacitating decompression sickness. Since such an operational procedure is considered dangerous by present criteria for explosive decompression, it may be necessary to develop some form of physical protection for aircraft personnel in the form of tight fitting clothing.

Positive and Negative Acceleration (Long Term)

Jet propelled aircraft have introduced no new problems in the field of acceleration but they have intensified the old ones made familiar by the dive bomber and the reciprocating engine fighter. The most significant change is an increase in the possible duration of the acceleration due to the greater time necessary to complete a turn at a given acceleration level when speed is increased. The intensity of the acceleration is limited by the structural stressing of these new aircraft, which differ little from the older conventional planes in this respect.

So far there has been little research on accelerations lasting longer than 15 seconds, but, in general, it is believed that tolerance is not significantly decreased by increasing the exposure time to 30 seconds. However, the physiological changes occurring during long term accelerations are more complex and determined by more factors than is generally appreciated. During positive acceleration there is a drop in the level of the diaphragm increasing the heart-brain distance and thus aggravating the gravitational decrease in arterial blood pressure at head level. During prolonged accelerations, pooling of blood occurs in the legs. A loss of plasma occurs leading to hemoconcentration, and there is a decrease in saturation of arterial blood due to gravitational disturbances in the lung circulation.

All of these may become significant factors in determining the exact level of acceleration tolerance. These effects combine to lead to cerebral and retinal hypoxia by decreasing the amount and the oxygen content of the blood flowing through the brain and eyes.

Certain factors will maintain cerebral blood flow during acceleration. An upward movement of the diaphragm is induced by anti-G suits and also by voluntary straining, thus shortening the heart to brain distance. Another factor is the prevention of venous pooling and fluid loss into the legs by anti-G suits and also by muscular action of the legs when tensing. In addition, the anti-G suit probably provides protection by obstructing arterial inflow into the lower extremities and so conserving blood for the head region. Further, the carotid sinus reflex compensates for acceleration by responding to the decrease in pressure in it by inducing an increase in arterial pressure. Another factor assisting continued blood flow through the brain during acceleration is the considerable suction effect (25-50 mm Hg at 4 G) exerted upon the blood emerging from the cranium by the venous column extending down the neck from the jugular foramina.

During acceleration lasting longer than 3 seconds, tolerance will depend on the vertical distance from heart to eye and to a lesser extent on the position of the legs relative to the trunk. In the average man this tolerance is 4.2 g for beginning visual symptoms and 5.0 g for blackout. Since the eyes lie forward of the heart by about 50% of the vertical heart to eye distance, bending forward will decrease the vertical heart-eye distance but backward reclining will

actually increase the distance until the subject has tilted to impractical angles greater than 45° from the vertical. This is why the 45° backward tilted seat offers no significant protection unless the legs are raised until the heels are level with the buttocks, and yet in a prone position in which there is an upward tilt of the trunk from the horizontal of 25°, subjects can endure 12 g without visual symptoms. The prone position might prove of value in certain types of jet aircraft in which high accelerations are permissible. The legs are of minor importance as a potential pooling region and their optimum position is transverse to the acceleration with the heels level with the buttocks.

Tolerance of 15 second accelerations is not greatly affected by heating the subject up to the point of sweating. Some preliminary work suggests that anti-G suits do not change this picture significantly. It is possible, however, that more prolonged accelerations indicate lower tolerance. In hypoxia, unless very severe, brief (15 sec.) accelerations show no change in tolerance.

No studies have been published with fatigued subjects, but it is probable that acceleration tolerance does not change unless the blood pressure is actually depressed by the fatigue. There is no evidence that there are serious chronic effects due to repeated applications of positive acceleration. Although some subjects have now worked in this field for five to ten years, none have shown cardiovascular changes attributable to the work.

Recently a number of interesting studies of negative acceleration have been published. Rushmer, Beckman and Lee have shown that the venous, arterial, and cerebro-spinal fluid pressures within the skull rise equally

during acceleration. This balance protects the intracranial blood vessels from overdistension, and cerebral hemorrhage probably does not occur during brief, 15 seconds, negative acceleration in the range of 3 to 5 g. Any unconsciousness occurring in this acceleration range may be due to the sequelae of reflex vagal cardio-inhibition due to overstimulation of the carotid sinus rather than to cerebral damage.

Pilots' Pneumatic Suit, Anti-G, for Positive Acceleration in Jet Fighter Aircraft

The USAF Type G-3 and G-3A pilots' pneumatic suits were used during World War II. These suits are cut-away, wrap-around garments, waist to ankle in length, covering only those regions which are actually pressurized, namely, the abdomen, thigh, and calf. The crotch and anterior and posterior knee regions are cut away. The suit is worn as an adjunct over the standard clothing. The garment was designed in this fashion because of the experience gained in the Eighth and Ninth Air Forces where the pilots desired to retain the use of the standard uniform in the event of being shot down over enemy territory.

The protection offered by the standard USAF Type G-3A suit ranged from 0.8 to 1.2 g. This protection, in general, was adequate in reciprocating engine type fighter aircraft where the relatively low speeds diminished the duration of high acceleration and limited the production of visual symptoms.

With increasing effects from acceleration on the pilot caused by increasing speed and maneuverability, the present standard Anti-G Suit (G-3A)

is inadequate without auxiliary muscular straining in many cases.

Research in methods of increasing man's tolerance to forces resulting from positive acceleration in jet aircraft led recently to the development and standardization of the USAF Type G-4A pilots' pneumatic coverall suit, anti-G. The average protection afforded by this suit is 2.3 g.

The G-4A suit is patterned after the USAF summer flying suit and clothes the arms, trunk, and legs. This suit, in contrast with the G-3A, which provides only four sizes with one size bladder for all suits, is fabricated in 12 sizes with bladders sized according to the size of the suit, which assures the better fit and protection for the pilot.

The lacing adjustments in the G-4A suit are of the piano hinge type and extend in one continuous piece of lacing from just below the groin to the ankle on each leg, and on either side of the lumbar region from a point just above the buttocks to the lower level of the last rib. This lacing adjustment increases the efficiency of pressure application to these regions.

The bladders for the G-4A suit consist of a single system of intercommunicating bladders made of neoprene coated nylon. This suit pressurizes a 20% greater area in all regions than does the standard G-3A suit. It further contrasts with the G-3A suit in applying some pressure to the buttock region which provides additional G protection.

Adjustment zippers are provided on either side of the lumbar region which, when unzipped, loosens the waistline and enhances comfort during ground operations.

It is anticipated that the maximum protection afforded during positive acceleration maneuvers using pneumatic type pressure suits will be in the range of 2.8 to 3.0 g. Suits offering more protection than those presently being standardized can be made only with a sacrifice of comfort during inflation. Experience has shown, however, that pilots will, in order to maintain superiority, accept some discomfort for protection. This may be attributed to the fact that present-day pilots, in contrast to the pilots of World War II, are better informed about the usefulness of anti-G equipment, through various training procedures as well as greater actual experience.

In summary, the larger bladder system, more efficient and continuous one-piece lacing adjustment, and greater range of sizes in the G-4A suit provide protection which is considered more adequate for present-day high speed aircraft.

Cockpit Design (Anthropometry)

Current requirements for cockpit dimensions are based on AF Technical Report 5501, entitled "Human Body Size in Military Aircraft and Personal Equipment", dated July 1946. The pioneer studies were made on the "Universal Test Seat", a piece of experimental equipment variable in every angle and dimension.

Seat comfort, however, depends not only on correct dimensions and angulation of the seat within the cockpit space but also on correct cushioning. Neglected in past years, this subject has recently received study and

development. Comfort tests are currently under way on a pulsating cushion designed to knead the buttock and thigh tissues, and thereby relieve compression fatigue.

In addition to the refinement of conventional cockpits, there has also been considerable interest in the development of "three-dimensional" controls for aircraft. This is a system whereby the pilot controls not only the aileron and elevator but also rudder by his hands. It is applicable to conventional seating and controls have been designed for this purpose, but actual tests are at present being confined to applications of the prone position for pilots.

Interest in the prone position began in the 1930's, when it was realized that airplane speeds could be increased by cutting down the cross-section of the fuselage to accommodate a prone pilot and that, at the same time, the pilot's tolerance to high G-forces could be increased. Many early prone position bed designs, however, were rejected because of the extreme discomfort encountered by pilots. Recent studies of the prone position have shown that pilots can lie in a properly constructed bed for eight consecutive hours or longer without discomfort. This new bed, in general, consists of specially shaped metal sides supporting a length of nylon netting. A counter-weighted headrest, a special jaw support, adjustable foot rests, specially designed three-dimensional controls, and adjustable cams for individual abdominal support are adjuncts to the bed.

Centrifuge tests have shown that pilots in this bed can tolerate 12 g for 20 seconds without blackout.

Flight tests of the new prone bed are currently being carried on. An installation has been made in the nose of a B-17, in which primary pilot training and preliminary dynamic tests of flight controls are being accomplished. A safety pilot is retained in the conventional cockpit to take control of the airplane at any time. Studies have also been made of the feasibility of an installation in the nose of a jet fighter, such as F-80, again with the retention of a safety pilot position.

Flight Instruments

Most of the instruments which the jet pilot faces are the same as those in comparable aircraft with reciprocating engines. Except for changes in scales to indicate higher speeds and higher rates of climb, and the addition of a maximum allowable pointer to the airspeed indicator to aid the pilot in avoiding excess compressibility speeds, flight instruments, in general, are unchanged from those in conventional aircraft.

Greater detail changes are found, however, among engine instruments, where some, such as the manifold pressure, coolant temperature and cylinder temperature indicators, are no longer needed, but other instruments have taken their places. The net total of instruments per engine, whether jet or reciprocating, is about the same. For bombers, where the number of jet engines is usually 4, 6, or 8, the total number of engine instruments becomes quite large. In the newer models, these instruments are designed and arranged for horizontal pointer alignment to simplify check reading.

At the higher speeds of jet aircraft, it is necessary for safety and for maintenance of a level flight altitude that the pilot spend relatively more time looking outside the cockpit. This reduces the time he may spend looking at instruments or charts in the cockpit and makes it more necessary for pilot to have as many as possible of his flight problems worked out before take-off. It also increases somewhat the chances of misreading a difficult instrument, such as the altimeter.

At high speeds the accuracy of flight instruments becomes more critical. A frequent complaint arises from inability to read pitch from existing gyro horizons with sufficient accuracy to maintain a stable altitude. Some pilots solve this problem by watching the rate-of-climb meter for evidence of pitch changes which are too small to be visible on the gyro horizon. Further difficulties are experienced with horizon indicators which become erroneous occasionally following prolonged turns and pull-outs. Future instrument design will reduce or eliminate this difficulty. As jet aircraft speeds approach the speed of sound, the pilot is particularly concerned with avoiding speeds at which a safe Mach number (the ratio of actual air speed to ambient speed of sound) for his craft will be exceeded. As a warning aid, a maximum allowable pointer has been added to the airspeed indicator. With increasing altitude, this pointer moves to lower airspeeds in conformity with the reduced speed of sound.

Navigation in jet aircraft is simpler but yet more difficult. The greater simplicity derives from the fact that as speed is increased wind

drift has relatively less effect on the course and ground distance covered. On the other hand, navigation is made more difficult because of the greater distance traveled during the time required to calculate an accurate position fix. Similarly, the time is reduced during which the pilot will remain in range of a ground station which transmits navigation or other information. Any errors of navigation, whether in the instruments or the navigational computations, are infinitely more serious in jet aircraft because of their limited fuel reserve.

Instrument flying is not yet as commonplace with jets as with other aircraft. Among the reasons for this are the relatively greater hazards from human and mechanical errors in instrument readings, the smaller fuel reserve with which to alternate destinations, the very high fuel consumption during landing procedures, the greater difficulty in pulling up and going around after a poor approach, and the lesser amount of instrument flying experience with jet aircraft.

Psychological Limitations

The high speeds of jet aircraft place a premium on quick reaction time. Pilots do many of the same things in flying jet aircraft that they do in flying other aircraft, but they have less time in which to carry out these activities. Instruments may be read more quickly and controls operated more rapidly. A moment's hesitation or a human error is much more serious than in slower aircraft.

Human reaction time is critical in many pilot acts. With closing speeds of 1,000 mph and more, only a few seconds may elapse between the time an approaching aircraft becomes visible and the time it has passed by. Pilots must pick up approaching aircraft or detect pips on a radar scope, decide what action to take, and then initiate and complete the correct response in a matter of seconds. For this they need instruments that are "human engineered" for the age of speed.

When emergency situations arise and the operator must respond under pressure of stress, human errors are most likely to occur in the interpretation of displays or in the operation of controls. He may become confused or do what is most "natural" rather than what he has been trained to do. It is essential, therefore, that both interpretation of instruments and required control movements agree with what is most "natural" generally. By taking advantage of these stereotyped tendencies, the job of training jet pilots also is greatly simplified. Significant progress has been made during the last few years in determining these "natural" response tendencies of pilots.

Environmental conditions occurring in flight can be shown to have a serious effect on psychological performance. For instance, it was found that an increase from 1-1/2 to only 3 g's results in a measurable increase in instrument-reading errors. This finding is particularly significant since the task used in this specific experiment was a relatively simple one as compared to the over-all task of flying a jet aircraft under conditions of high G. Additional problems arise because the pilot experiences difficulty in reaching

around the cockpit and in moving controls under conditions of increased G. This problem is being solved partially by placing more controls on the stick or wheel but this in turn raises many psychological problems of switch design and placement. Other variables, such as temperature and vibration, also show psychological effects before extreme physiological states are reached.

Pilots of jet fighter planes rely greatly upon the "feel" of the stick during gunnery attacks or evasive action, with occasional reference to the Mach meter, accelerometer, altimeter, and gyro horizon. The "feel" of the back pressures exerted by the flight controls provides the jet pilot with early approximate information of what the plane will do as a result of his control actions before the plane and its instruments have responded. Because of the tremendous forces required to move the control surfaces of high speed aircraft, boost systems between the pilot's controls and these control surfaces are required. Jet pilots, therefore, do not have the same direct pressure feed-back or "feel" on the stick which is present in slower type aircraft. Further, when airspeed gets very high a situation may arise where control-force reversals occur. Right aileron pressure may actually cause the aircraft to roll to the left! Pilots obviously must be very alert for these critical points. They must continually sample aircraft response and sense changes in stick forces, because at very high speeds instability of control may cause the aircraft to disintegrate in a matter of seconds. All this requires study of human response characteristics when the pilot is considered

as a part of the total servo-boost control system. Research on this problem is proceeding in close cooperation with servo engineers and aerodynamic experts.

Cockpit Temperatures

High speed aircraft are heated significantly by the frictional impact of air on their surfaces and by the ram rise and heat of compression of air to their ventilating systems. The combination of these heating effects is known as aerodynamic heating. The more molecules of air that the aircraft encounters in a given time interval, the greater will be the aerodynamic heating. Therefore, the most extreme heating will be encountered at sea level where the air is the densest. It is estimated that, without artificial cooling, the equilibrium temperature in the cabin of an aircraft traveling at 650 mph at sea level may be as much as 70°F. above the outside ambient temperature, due to aerodynamic heating alone without the added contribution from solar radiation. Because of the limited sea level operations with jet aircraft today, there has been no serious report of any operational difficulty introduced by aerodynamic heating. (The world speed record, established in the summer of 1948 at Muroc, was made in an F-86 without any auxillary cooling.) This situation will probably continue to exist in the near future, as all newer jet fighters are equipped with efficient cabin air-cycle cooling systems.

Even under the worst conditions -- failure of the air conditioning system during low altitude, high speed flight on a hot, summer day --

anticipated temperatures are within physiological tolerance limits for the flight times now possible. This is shown by a study of human tolerance for high temperatures recently carried out by the University of California under contract with the Air Force. This study revealed that the absolute upper limits of tolerance are:

TEMPERATURE °F.	TOLERANCE TIME Minutes
160	60+
180	49
200	33
220	26
240	23.5

In their experiments, air and wall temperatures were the same, humidity very low, and their subjects wore heavy, long underwear (1/2 clo insulation). More clothing insulation would have increased tolerance times above those indicated. Tolerance was considered to have been reached when the subject could not "take it" any longer. At this end condition, heart rates were approximately 150 per second, skin temperature approximately 105°, and rectal temperature about 100°F. Other symptoms include faintness, nausea, tingling sensations in extremities, mental confusion, compulsive restlessness, and dyspnea. Practical limits for Air Force use might be arbitrarily taken as half the times indicated above until more information becomes available. The limiting temperature at which room air can be breathed is approximately 240°F.

A new system of personal thermal protection is under consideration, which is designed to compensate automatically for large and rapid changes of cabin temperature. Air of proper temperature is blown under flight clothing

near the skin by a system of flexible air ducts. Test chamber subjects, dressed in a coverall and an intermediate weight flying suit over a basic ventilating system, have been kept in thermal balance indefinitely by such a system through the temperature range -30°F. to +180°F. There is every reason to believe that this range can be extended considerably. Air conditioned clothing allows a greater range of aircrew comfort for a given amount of personal equipment and permits choice of outer flying garments largely on the basis of survival conditions likely to be encountered.

Sound Problems Associated with the Operation of Jet Propelled Aircraft

The possible disabling action of ultrasonic frequencies (20,000 cps and upward) present in the sound fields generated by jet and rocket propelled aircraft has been much publicized. Currently available data indicate, however, that the ultrasonic frequency components of these sound fields constitute no serious hazard to man. Less than one half of one percent of the acoustic energy present in ultrasonic frequencies is absorbed from the air by the human body. In the same frequency range, fur bearing animals (rats, guinea pigs) absorb from air more than 12 percent of the acoustic energy present. In these animals the absorbed acoustic energy is converted to heat with a resultant rise in body temperature. Only when the level of acoustic energy is 150 db above the standard reference level (10 db watts cm^2) is the quantity absorbed sufficient to raise the animal's body temperature

to a lethal level. The acoustic energy generated at ultrasonic frequencies either by jet aircraft in flight or by the power plant on the ground has been found <u>not to exceed</u> 120 db above the standard reference level. This acoustic energy level is one thousand times less than that required to kill fur bearing animals. No ill effects have been observed in men exposed to those levels of acoustic energy (150 db or above) in the ultrasonic frequency range which have killed fur bearing animals. Man is protected by a smaller coefficient of absorption, by a greater heat capacity, and by a greater capacity for heat elimination. It is, therefore, unlikely that the acoustic energy levels (ultrasonic frequencies) generated by current models of jet propelled aircraft will be injurious to man.

The spectrum of audible frequencies extends from 20 cps to 20,000 cps. A narrower portion of this spectrum, extending from 100 cps to 6,000 cps, is very important for intelligible speech communication. The effects of sound, in the speech frequency range, generated by jet and rocket propelled aircraft, are of major importance in aircraft operations.

Any noise containing energy in frequencies present in human speech will, if at a level above the threshold of hearing, "mask" human speech, that is, it will elevate the threshold of hearing for speech sounds. The higher the noise level is above the threshold of hearing, the more extensive the masking becomes. In addition, noise of high energy content in this frequency band will produce an actual temporary deafness and may produce a permanent deafness if the exposure is repeated and is of long duration.

Although jet propelled aircraft are generally considered more quiet than conventional aircraft, actual comparison of the sound levels measured in a standard jet propelled aircraft and in a conventional aircraft propelled by two reciprocating engines, while flying at normal cruising speeds, reveals a higher level in the jet aircraft, as may be seen in the following table:

FREQUENCY:	0 to 75cps	75 to 150 cps	150 to 300cps	300 to 600cps	600 to 1200cps	1200 to 2400cps	2400 to 4800cps	4800 to 8500cps
Noise Level:	-3db	-12db	-5db	+9db	+19db	+22db	+21db	+21db

The sign (-) indicates less noise and the sign (+) indicates more noise inside the jet aircraft than inside the conventional type. Throughout a large part of the audible frequency band, the noise level in the jet propelled aircraft is higher than in the conventional. This fact is more significant when it is realized that the higher noise level of the jet airplane is in the frequency band most critical for speech intelligibility, that is, from 300 cps to 3,000 cps. The noise field of a jet aircraft is extremely effective in masking speech and is of such an intensity level that it will raise the human threshold for speech by about 100 db above normal. This increase in threshold is sufficient to render direct speech communication totally impossible and to render communication by radio and interphone extremely difficult unless unusually well fitted helmets and head phones are worn. In addition, exposure to this sound field for 30 minutes or longer can be expected to produce a temporary hearing loss of 20 db or more.

The operation of jet power plants in test cells or jet aircraft on the flight line exposes nearby personnel to sound levels of about 130 db above

the standard reference. This level is constant for all frequencies in the audible range. The effect on understanding speech, the deafness produced, etc. will be even greater than in aircraft during flight. One may expect the threshold for speech to be raised by about 120 db. Thus, in ground operations one is confronted with all the problems encountered in flight but in a greatly magnified form.

The protection required for personnel will be greater in the case of ground operations. At present, the protective measures which can be taken are: (1) use of ear plugs, for example Mine Safety V-51R ear defenders, individually molded, plastic plugs, wax impregnated cotton plugs; (2) use of well fitted helmets, equipped with headphones held by doughnuts which seal tightly around the external ear. Either method alone may be adequate in the aircraft, but the combination of both methods is required on the ground.

In the special case of engine test cell operations, the combined methods are not entirely adequate and it is, therefore, essential that test cell operators spend a minimum length of time in the test cell sound field. It is also essential that the control-observation room of test cells be isolated by rigid, tight walls from the test cell proper and that sound treatment be applied to reduce the control room sound level to 85 db above the standard reference level. Direct speech communication will then be possible.

In the sound field near jet engines, parts of the body, the skull, the jaws, the thoracic wall, and large muscle groups appear to vibrate. Low

frequency sound fields from a siren produce similar senations. It is now believed that many of the effects ascribed to ultrasonic frequencies may be induced by these low frequencies. Thus, the nausea, fatigue, or locomotor disturbances produced by a sound field probably are caused by frequencies below 200 cps. Further experiments are required to evaluate properly the effects of very low frequency sound and vibrations.

Ejection Seat

The pilot ejection seat which has been discussed for so long is now being released for operational use in certain aircraft. All F-80C's and F-86's have operable seats. The F-84 ejection seat will be released in Spring 1949. In the bomber class, such as the B-45 and the B-47, ejection seats are planned but as yet are not operable.

The catapult which propels the seat from the airplane pushes the seat for 65 inches with an acceleration time curve that approaches an ideal shape and imparts a velocity to seat and man of approximately 62 feet per second. The maximum allowable accelerative force on the man is 16 g. The required velocity can be achieved at this relatively low acceleration only if the rate of change of acceleration is kept below 150 g's/sec. Higher rates of change excite the complex elastic system consisting of the man, the seat-cushion, and seat as a unit. Vibrational energy absorbed in this system will result in high acceleration peaks on the pilot. The duration of acceleration is so short that no blackout is experienced. The actual sensation experienced in an upward ejection is not unpleasant, since there is no acute jolt, only a strong and steady push which lasts a little less than a quarter of a second.

Test ejections with dummies have been made from a F-80 and F-82 at speeds up to 450 mph indicated and have been made in spins, dives, during pullouts, and in turns. The catapult thrust has proven adequate to propel the seat

clear of the empennage with a sufficient margin at speeds tested to indicate that it will be adequate at speeds up to 600 mph indicated. Human volunteers have tested the Air Force seat from a F-61 at a speed of approximately 300 mph.

In the ejection seats now released for use, the pilot frees himself from the seat after he is ejected by opening his safety harness. He must then open his parachute. He is cautioned to release himself from the seat as soon as possible after ejection and delay opening his chute as long as possible to prevent collision of the empty seat with his parachute canopy. If he is at high altitude he is advised to free fall to levels below 20,000 feet in order to reduce parachute opening shock and the danger of hypoxia. Present development of the ejection system is being directed toward completely automatic operation once the pilot pulls the trigger to eject himself. In the projected system, the lap belt will have a built-in barometrically controlled automatic release, which opens and allows the man to separate from the seat under the following conditions:

(1) Above 20,000 feet, separation will be delayed until this altitude is reached.

(2) Below 20,000 feet, release from the seat occurs three seconds after ejection.

When the pilot separates from the seat, a static line connected to the seat pulls the parachute ripcord. Manual operation of the lap belt and ripcord can be made prior to automatic operation. A drag parachute about 40 inches in diameter will be attached to the seat itself and will open automatically

about one second after ejection. The purpose of this drag chute is three-fold: first, to stablize the seat; secondly, to decrease the time for seat to decelerate to speeds safe for parachute opening; and thirdly, to insure separation of man and seat. Since there is some danger of collision between the empty seat and the pilot's open parachute canopy under certain conditions in an automatic sequence, a second parachute of about 18 feet in diameter, called an anti-collision chute, may be necessary on the seat itself. This second parachute will open up as soon as the pilot separates from the seat and prevent the seat from colliding with the pilot or his open parachute.

As a result of a number of factors in ejection seat design, the present Air Force seats have been observed to tumble after ejection. From observations during ejections from a TF-80, this tumbling, however, is not considered a serious risk for the pilot at speeds below 500 mph indicated. By careful choice of the seat's aerodynamic design, it may be possible to eliminate tumbling at higher speeds.

Among other designs of ejection seats that can be compared with the Air Force seat described above is the Martin Baker seat, which has been adopted by the RAF and is being followed very closely in principle by the U. S. Navy. Its unique feature is the head curtain method of firing. The trigger curtain is stored in a container back of the head rest and is pulled down over the face with two hands when ejection is required. A curtain offers the advantage of physical protection from airblast as well as assuring that the head is properly positioned along the axis of ejection before the

catapult is fired.

It is to be expected that many pilots will not readily accept this new method of escape until it has been demonstrated in practice. While this may well deter them from using the seat at lower speeds where they believe they have a chance of escape by a conventional exit, the seat offers the only positive method of escape at transonic speeds or under positive G occurring during a spin. In order to familiarize pilots with this new escape device, a program of training is required to teach the operation of the equipment. A training tower is to be erected at a jet fighter station where pilots can experience firsthand the accelerative forces imposed by the catapult. It has been found that such a ride goes a long way toward relieving natural skepticism and fear by demonstrating the relatively mild force imposed by the catapult.

Protective Helmets

The need for a protective head covering during normal operations and crash landings of present day jet propelled aircraft is demonstrated by statistics that show the head is the most frequent site of single injury occurring in crashes. During normal flight, a good protective helmet should minimize the effect of buffeting in rough air or violent maneuvers, afford maximum acoustical attenuation, present a refleoting surface to incident infra-red, be comfortable for relatively long periods, offer some protection against low energy missiles, be light enough neither to

tire the pilot nor to become unmanageable during maneuvers, neither restrict vision nor interfere with the oxygen equipment, in normal use or in the event of its loss during bailout.

Since the brain is a mass having a gelatinous consistency cushioned by its surrounding fluid medium, covering membranes and associated nutrient vessels, within a rigid cavity, it is susceptible to injuries of the following causes: (1) Angular acceleration of the skull relative to the brain; (2) Penetration of the skull with subsequent penetration of the brain; and (3) Deformation of the skull either with or without fracture and the subsequent relative motion of adjacent parts of the brain. It is felt that all others, such as "coup and countre coup" or cavitation can be shown to be either negligible in effect or a subheading under one of the three mentioned above.

The idea of a protective helmet has several fundamental limitations, for example, angular acceleration of the skull will occur in all cases where the line of the blow does not pass through the center of gravity. Unconsciousness or death may occur without fracture or even serious deformation of the skull because of rotation of the skull relative to the brain, bringing about so-called "coup and countre coup" types of injury. It is almost impossible to reduce angular acceleration by a significant amount with the use of a helmet. The greatest present need is for a study of the mechanics of brain injury and an evaluation of brain tolerance to angular acceleration and deformation.

There are several types of protective helmets being worn by Air Force pilots. The recently standardized P-1 is numerically the most common, there

having been received approximately 1,700 from the manufacturer to date. The second most common helmet is the Type 1, Mine Safety Appliance Company's helmet, of which about 750 have been received from the manufacturer to date. There is also a small number of the much publicized "Toptex" or Lombard helmets, manufactured by Protection Inc., and a special design by Naval Air Experimental Station. In general, none of the helmets now in use by Air Force pilots meet satisfactorily all the requirements mentioned above.

There are two general types of energy absorbing systems used between the shell and the head. One consists of a leather sweatband held away from the shell by rubber pads or cord suspension. A series of longitudinally directed webbing strips converging at the top of the shell but not fastened to it are attached to the sweatband. This method absorbs horizontal blows from any direction by means of the pads or cords attached to the sweatband. Blows from the top are absorbed by stretching the longitudinally positioned cords. The alternative method of reducing the acceleration of the head and absorbing energy is to place a layer of cellular plastic or other material between the shell and a thin layer of sponge rubber and leather. The sponge rubber is necessary to minimize the number of pressure points on the head and cause the helmet to fit as many head sizes as possible, since the cellular plastic is not deformed by pressures in the comfort range. The webbing suspension is used in the P-1 and Mine Safety Appliance Company's helmet, while the cellular plastic is used in Protection, Inc. helmets.

Preliminary tests seem to indicate that for force distribution purposes the standard P-1 and Mine Safety Appliance Company's shells are adequate. The

Protection, Inc. shell is considered to be too flexible, that is, there seems to be little tendency to distribute a blow which is great enough to compress the cellular cellulose acetate suspension. In regard to protection against flak, very little work has been done, but it is believed that none of the present helmets offer appreciable protection. The reflectivity with respect to incident infra-red radiation is of the same order of magnitude for all three helmets and is adequate.

The solution of the problem of acoustical attenuation depends to a large extent upon the pilots themselves. The headphone assembly and seal in all the helmets attenuate sound rather well if properly adjusted.

The question of helmet weight is of prime importance. Most protective helmets being used today weigh on the order of two pounds. Since the average head weight is approximately 10 pounds, every pound of helmet weight is about a 10% increase in force applied by the neck muscles in moving the head. During a 5 g maneuver, a two-pound helmet will have an apparent weight of 10 pounds. Forces of magnitude much greater than this when suddenly applied might easily cause the head to become unmanageable and crash into the cockpit walls or gunsight.

The possibility of bailout at high speeds and high altitudes necessitates an absolutely sure method of retaining the pilot's oxygen equipment in the event his helmet should be blown off. To cover this contingency, a modification of the P-1 helmet is being standardized whereby the oxygen mask and headphones will be integrated with a regulation A-11 leather or A-10A cloth helmet. Loss of a protective helmet should never deprive a pilot the use of his oxygen equipment.

Wind Blast Protection in High Speed Flight

Adequate escape systems in high performance aircraft necessitate protecting the escapee from high velocity wind blasts. The problem is one of two-fold importance, for protection of the individual must be accompanied by protection against loss of oxygen mask and helmet in the wind stream. When a pilot leaves the cockpit he is subjected suddenly to the full blast of the slip stream which then decreases until terminal velocity is reached. The force of this blast has been estimated as being approximately 5,000 pounds on an upright man traveling 500 miles per hour at sea level. Such a force, combined with the aerodynamic properties of existing helmets and oxygen masks, is sufficient to tear these devices from the head, leaving it fully exposed. To date, the present protective helmet and mask combinations have failed to remain on the head during dummy ejections at velocities over 300 mph.

Experiments carried out in Germany in 1943 (reported by Lovelace in Memorandum Report TSEAL-3-696-74C) using first a wind tunnel and then a pressurized chamber to produce an air blast, indicated that subjects with faces unprotected could successfully withstand blasts up to 531 mph velocity lasting for 1.5 to 2.0 seconds, if the blast did not occur unexpectedly. The mouth had to be held firmly shut and extreme effort was used in an attempt to hold the eyelids together. In spite of the action of the palpebral muscles, the eyelids were seen to balloon but with no damage to the eyeballs. The U. S. Navy and NACA conducted similar experiments in a wind tunnel at Langley Field in 1945, where several subjects successfully

withstood blasts up to 420 mph. It has been calculated that in the upper limits of sonic speed at sea level, deceleration to 400 mph following ejection occurs in from .5 to .75 secomds and at 40,000 feet, it occurs in about 2 seconds. Blasts of greater magnitude than 530 mph at sea level may cause dangerous vibrations and waves in facial tissue resulting in tearing.

To assist in overcoming hazards due to wind blast, the RAF and the U. S. Navy use a hand held curtain on their ejection seats. This curtain has its main advantage in its action as a restraint for the oxygen mask and helmet. There are further protective actions in preventing forward movement of the subject's head during ejection and in preventing some vibrations and waves in facial tissues; however, blast pressures will be transmitted directly through the curtain. Under high g forces or violent changes of altitude of the aircraft prior to ejection, the escapee might encounter serious difficulty in being able to reach above his head to grasp the wind curtain. The use of the curtain also precludes the weight sparing effect of arm rests. Arm rests will support from 25 to 50 percent of the weight of the head, arms, and upper trunk, thus sparing the lumbar spine during ejection,

The U. S. Air Force is at present interested in all types of wind blast protection, but attention and energies are directed more towards the development of an adequate oxygen mask, helmet, and visor combination. Such a combination must be of a design which will enable it to withstand pressures up to 1,200 pounds per square foot and at the same time present a reacting surface to the wind stream, which will contribute as little as possible to aerodynamic forces tending to wrench equipment from the head. Such a

helmet-visor-mask combination is now undergoing rigorous tests in pressure chamber blasts and dummy ejections. The ultimate design for future use may be a protective helmet unit in which oxygen supply, protective pressures, temperature regulation, and complete facial coverage will be incorporated.

Vision

The high speeds and altitudes attained in jet aircraft in a number of ways increase the demands placed upon the pilot's vision. The G-forces in turns and pull-outs are more intense, longer in duration, or both. As a consequence, the pilot must pay greater attention to the avoidance of excessive G-forces in order to prevent partial or complete visual blackout. Any loss of vision must be avoided, if possible, because of the great reliance the jet pilot places upon vision for avoiding dangerous aircraft attitudes and flight obstacles.

The reduced turning or maneuvering radius and higher closing rates associated with the speeds of jet aircraft force the pilot to pick up and identify his targets at much greater distances. Unless a target is picked up at considerable distance or happens to be directly in his path, the jet pilot will not be able to make the necessary turn required to bring the aircraft into firing position. Flight obstacles must likewise be detected at greater distances in order to be evaded. This need for split second vision at greater distances places a premium upon high visual acuity, and emphasizes the need for clear windshields without optical distortion. It

emphasizes also the need for the pilot to be thoroughly trained and briefed concerning the location and appearance of his targets and any flight obstacles which he might encounter.

Less serious than the increased emphasis on visual acuity is the general reduction in use of lateral vision. When near the ground in strafing attacks, objects move by with such high relative velocity that only those directly forward are seen clearly. At altitude, although ground objects at the side can be seen clearly, the increased speeds force the pilot to concentrate more on the visual area directly ahead.

At the very high altitudes where jets perform best the visual surroundings are considerably changed. With increase in altitude, there is less haze, and the sky becomes much darker, while the direct rays of the sun become more intense and contain a higher proportion of ultra-violet rays. As protection against the ultra-violet radiation and the intense sunlight, the wearing of sunglasses becomes more essential. Because of the darkened sky, the contrasts between sunlit areas and shadows are increased. The shaded corners of the cockpit are darker and harder to see into, while the sunlit areas are more glaring. Other aircraft, instead of appearing as dark shadows against a light sky, are more likely to appear as bright spots, depending upon the direction from the observer in relation to the sun. Because of the changed visual conditions, judgment of distance is often erroneous.

THE FUTURE

The future direction of aero medical research and development is obvious. Protection of airmen under emergency conditions in a vacuum (or at unlimited altitude), tolerance to very high radial G-forces acting for very long periods of time, tolerance to rotational or spin forces about axes through the body, and tolerance to extremely high temperatures caused by long flights at many times the speed of sound, must all be considered. Extreme simplicity must be the keynote in designing cockpit layouts and their associated instruments and controls. In short, aero medical research will continue to be asked to do tomorrow what is the impossible today.

From reading the previous synopsis, it is at once evident to the flight surgeon and the aviation physiologist that research progress on the aero medical aspects of jet flight since the war has been steady. Such progress is always measured by its contribution to the improvement of flying efficiency of flying personnel. In the final analysis, the airman evaluates this progress from results of actual human experimentation performed in his service laboratories and in actual flight. Animal studies in the altitude chamber and on the centrifuge, and engineering evaluations in test chambers and with dynamic models in flight are all contributory methods of research and development that reduce the calculated risks of human experimentation to a minimum. Such risks in the end are necessary to demonstrate to airmen that the principles and methods proposed are sound. In this period of peace the

incentive for human experimentation must be kept alive by ever continuing diligence, thoroughness, and patience on the part of the flight surgeon and his team of allied scientists and engineers.

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